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DEVELOPMENT AND ADAPTATION OF HYBRID ALGORITHMS FOR ASSESSING THE DEGREE OF WELL INTERACTION

R. A. Gilyazetdinov, V. Sh. Mukhametshin*, A. A. Gizzatullina, E. M. Kochanov,
L. Z. Samigullina, R. R. Stepanova, L. B. Akhmetianova, R. N. Bagmanov
Institute of Oil and Gas, Ufa State Petroleum Technological University (branch in Oktyabrsky), Russia

ABSTRACT

In the presented work, a comprehensive analysis of geological and commercial data on three low-yielding deposits associated with the East Orenburg arch was carried out. Based on the use of the methodology for calculating statistical values of the truncated normal distribution, a formula is proposed adapted for unproductive facilities, the drainage of which is carried out using special technologies and equipment (short-term periodic operation mode) and (or) in a classical way with an unstable supply coefficient of deep-pumping equipment. Based on the comparison of the obtained intermediate and main research results, the regularities of geological, technological and operational characters have been established, which significantly improve the efficiency of planning and conducting various geological and technical measures. The general trend of similarity in quantitative and qualitative ratio is highlighted, which allows us to use this to solve specific problems of effective development of low-productive deposits of carbonate reservoirs.

Keywords: mechanized well stock; geological and statistical models; mathematical modeling; deep pumping equipment; oil recovery coefficient; hydrodynamics of reservoir processes.

Introduction

It is known that the problem of involving residual reserves (OZ) of liquid hydrocarbons concentrated in low-yield reservoirs in the development is widespread within various oil production facilities [1-6]. In particular, it remains relevant for large deposits of the Ural-Volga region, which to this day remain the key energy foundation of the country [7-12]. According to preliminary calculations, the average residual value of oil reserves (as a percentage of balance reserves) in low-productive reservoirs of large facilities of the Volga-Ural Oil and Gas Province (VUNGP) varies from 4.3 to 37.9%, and in some areas reaches 50%, which leads to the need for a rapid pace of development of scientific and methodological approaches to form a relevant development strategy resources.

The development of low-yielding deposits is associated with a number of difficulties and uncertainties arising from the unfounded predictive models of oil displacement, algorithms for planning geological and technical measures and ideas about the mechanisms of fluid inflow to the well. A number of papers [13-18] are devoted to the study of the most important aspects of successful drainage of deposits associated with various tectonic elements of the VUNGP, in which researchers, based on the results of various experiments, agree on the ineffectiveness of using practices for the development of terrigenous reservoirs in improving the exploitation systems of carbonate reservoirs. The main difficulty in realizing the most effective development of them is associated with various difficulties, including extremely unfavorable geological conditions, reflected in the form of:

- uneven oil saturation of the pore space;
- heterogeneous values of porosity and permeability;
- discontinuity of the distribution of reservoirs within the stratigraphic elements, their significant facies variability;
- ambiguity of estimates of fracturing and cavernosity of rocks based on the results of direct and indirect studies [19-23].

In addition to the above, another important aspect of the rather low efficiency of the development of carbonate reservoirs in the Ural-Volga region is the difficulties of an applied and technological nature that arise when forming a strategy to increase the flooding coverage rate in areas where residual reserves promising for extraction are concentrated [24-26].

Materials and methods

As a rule, in order to increase the productivity of wells and optimize the technology of oil displacement in the fields of the Ural-Volga region, hydrodynamic methods of increasing oil recovery are used, based mainly on changing the directions of filtration flows, which cannot always be fully realized in conditions of occurrence of carbonate reservoirs [27-30]. This leads to the formation of a number of field tasks, among which one of the most urgent is the implementation of effective management of oil displacement processes from

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**E-mail:* vsh@of.ugntu.ru
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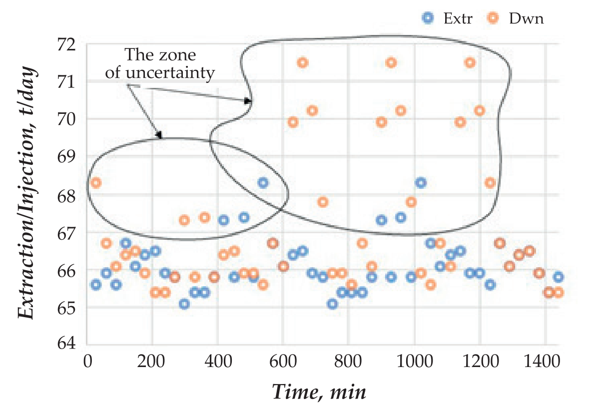

Fig. Identification of a non-permanent zone of uncertainty based on a comparison of daily series of injection and extraction of liquid (well XX9, IV area, Askyn horizon, Bashkir vault)

unproductive deposits based on a comprehensive assessment of the degree of interaction of the elements «producing well-injection well» in nonlinear systems.

The problem of monitoring and controlling flooding processes in real time is closely related to various circumstances that everywhere affect:

- the success of the most important technological operations of oil production;
- implementation of mechanisms for regulating the rate of extraction and selection of liquids;
- sustainability of planning a number of geological and technical measures and improving the quality of management decision-making.

Studying the issues of identifying the degree of interaction between wells requires an integrated approach to the analysis and screening of accumulated geological and field data, taking into account the influence of technological processes and the peculiarities of the conditions of occurrence of productive formations identified during the interpretation of the results of geophysical and hydrodynamic studies [31]. To create a portfolio of planned industrial works to increase oil recovery, an important aspect is to take into account the interference of wells with each other and express it through a number of quantitative and qualitative characteristics. A classic example of determining the tightness of the connection between a production and injection well is the calculation of the Spearman coefficient using time series of flow rates and fluid injections. This method has found wide application, mainly on highly productive objects of terrigenous reservoirs, the geological and physical characteristics of which coincide with each other and have an insignificant indicator of variability.

One of the most important reasons for the inaccuracy of using methods based on calculations of the correlation force and their further assessment on the Cheddock scale is the bias of the results for wells operated by mechanized methods in a short-term periodic regime (KPR), the proportion of which from the total number of low-productivity wells varies from 12 to 75%. The choice of the presented oil extraction technology is due in most cases to the technical and technological impossibility and economic unprofitability of efficient operation of wells with constant liquid extraction due to their low productivity or a number of auxiliary complicating factors (high coefficient of removal of mechanical particles, significant gas factor, waterlogging, etc.). The complexity of analyzing time series of flow rates and downloads for wells operating in the KPR and making effective management decisions based on its results lies in the formation of a non-permanent zone of uncertainty (fig.) due to the operation of deep pumping equipment under the «work-accumulation-work» program [32]. Its significant variability is due to the intensive dynamics of the processes occurring in the «TUBING-pump-formation» system.

At the same time, the cyclical nature of the processes of accumulation and extraction of liquid contributes to the formation of a nonlinear front of intense liquid vibrations in the bottom-hole zone of the formation, which in turn leads to:

- uneven redistribution of pressure within the fractured-porous media of productive formations;
- changes in the productivity of producing wells;
- significant variation in numerical indicators of well interaction;
- reducing the volume of potentially recoverable resources [33-35].

The above aspects in one or another plane of research confirm the need to create hybrid algorithms for determining the degree of mutual influence of wells at facilities represented by low-yield deposits of VUNGP, both for wells operating in the classical mode with unstable inflow and in the mode of short-term periodic operation (KPR). By the term «hybrid algorithm» we mean an algorithm with the following properties:

- takes into account various hidden patterns of parameter changes reflecting the geological heterogeneity of objects when assessing mutual influence;
- allows you to implement an adjusted calculation of the mutual influence indicator through a number of complex and reference parameters, which contributes to a significant expansion of its scope for solving problems of oil field development using a limited amount of data;
- fully characterizes the variability of geological and physical characteristics of deposits by implementing the initial stage of modeling using the criterion of «stratigraphic confinement»; in addition, it allows you to apply the results obtained on objects that are analogous to the geological complexes considered in this work.

Results

To implement this task, a generalized geological and commercial database was used for more than 150 producing and injection wells that uncovered deposits of carbonate reservoirs of the roofing part of the Artinsky tier, Fransky tier and Afoninsky horizon of the Eiffel tier, located within the south of the East Orenburg arch (VOS). The deposits are characterized by low productivity, a dense grid of producing wells and significant variability in indicators of the water content of the extracted products, the gas factor, compensation for injection sampling and distances to injection wells. When analyzing the geological conditions of the occurrence of productive formations, a high heterogeneity in the density of the distribution of porosity parameters in geophysics, effective oil-saturated thickness, and permeability was noted [36].

Collectively, the above factors in various natures affect the degree of interaction of wells with each other and require the formation of a differentiated approach to the process of conducting geological and statistical modeling operations. Based on this, further preparation of the initial data sample was carried out separately, depending on the stratigraphic proximity of wells to a particular geological complex. The ratio and strength of correlations for three groups of objects according to the most significant geological and commercial and technical and technological parameters, identified on the basis of screening and monitoring of the history of deposit development, are presented in table 1.

The following parameters were used for the analysis: h_{ef} – effective oil-saturated thickness; m_c – core porosity; μ_o – oil viscosity; G – the gas factor; k_{per} – permeability coefficient; m_g – porosity in geophysics; P_{sat} – saturation pressure; ω_m – porosity variation; K_{pr} – the proportion of reservoir rocks in the total thickness of the reservoir; σ_m – the RMS value of porosity; K_f – the coefficient of fragmentation of the formation; K_o – oil saturation coefficient; Q_o – oil flow rate; Q_{liq} – liquid flow rate; W – water content of products; P – the pick-up rate of injection wells. The choice of these parameters is due to a significant range of characteristics that they reflect. In addition, when conducting discriminant analysis, they largely provide more than 80% of the identifiability of objects, which indicates a high level of their stability within the framework of the modeling procedure.

The analysis of the r indicators allows us to say the following:

- for deposits confined to the Artinsky tier, a strong inverse relationship can be traced for the parameters characterizing the reservoir's reservoir filtration properties;
- for deposits confined to the French and Eiffel tiers, a strong direct relationship can be traced for parameters characterizing the physico-chemical properties of fluids;
- for the French tier, the density of the distribution of parameters and numerical indicators of their relations in columns 1, 3, 5 is heterogeneous, unlike the Eiffel and Artin tiers;
- insignificant in strength, but identical in direction, the relationship can be traced between the parameters of the intake capacity of injection wells and permeability for three tiers;
- a high level of correlation has been established between the statistical characteristics of geological and physical parameters (thickness properties of the formation) for all three objects (see column 6).

The primary analysis of the data in a differentiated manner, depending on the stratigraphic proximity of the objects, revealed a number of factors that defy superficial logical interpretation, and in some aspects contradict the physical component of the hydrodynamics of formation processes, which requires further detailed research [37]. So, in columns 8, 9, 10, 11, the values of correlations for the technological parameters of well operation and the permeability parameter are determined. The choice of an indicator characterizing the reservoir's reservoir filtration properties is due to the fact that it has a significant impact on the productivity value. The obtained indicators of r correlations vary significantly in numerical equivalent and sign, which indicates significant differences between the mechanisms of fluid movement in a porous medium within various stratigraphic elements [38]. At the same time, the parameters in the above-mentioned columns and their derivatives (water content) differentially in three deposits obey the normal distribution law, which allows us to use the methodology for restoring the values of the parameters of the classical distribution as a further stage in the development of the algorithm [39].

Let's assume that the producing well is operating in a short-term periodic mode with technological indicators Q_o, Q_{liq}, W. The pick-up capacity of the injection well surrounding it is P. The cycle of accumulation, injection and extraction of liquid is characterized by both truncated and normal distributions, which can be represented as histograms approximated by functions of the form (1):

$$n = \frac{i_j}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\frac{\left(x - \overline{x}\right)^2}{2\sigma^2}} \qquad (1)$$

where n – theoretical frequencies; i_j – a complex indicator characterized by the product of the total number of observations (including unknown ones) N and class size h; by j=1 – producing well, $i_1 = N \cdot h$, since there is a truncated distribution for technological parameters due to the operation of the well in the KPR and (or) unstable inflow; by j=2 – injection well, i_2=1, due to the fact that the injection of liquid is carried out according to the standard scheme; σ – variance of the original data sample; $\overline{x}$ – the average value of the data sample.

To determine the values N, σ, $\overline{x}$ which will be used in determining the degree of mutual influence of wells, we prolog equation (1) and, using the degree property, we obtain (2):

$$\ln n = \ln \frac{i_j}{\sqrt{2 \cdot \pi}} - \ln \sigma - \ln \frac{\left(x - \overline{x}\right)^2}{2\sigma^2} \qquad (2)$$

Table 1

The results of constructing correlation matrices for restoration objects

Stratigraphic dating	**The value of r correlations between the parameters***										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	h_{ef} **and** m_c	μ_o **and** G	k_{per} **and** m_g	P_{sat} **and** μ_o	ω_m **and** K_f	σ_m **and** ω_m	K_f **and** K_o	Q_o **and** k_{per}	Q_{liq} **and** k_{per}	W **and** k_{per}	P **and** k_{per}
Artinsky tier	0.581	-**	-0.71	-**	-0.21	0.587	0.555	-0.45	0.329	-0.26	-0.32
The Frankish tier	-**	-0.67	-**	0.267	-**	0.681	0.482	-0.59	-0.66	0.326	-0.19
Eiffel Tier	-0.44	0.554	0.455	0.303	-0.28	0.403	0.394	0.398	-0.14	0.577	-0.22

* *the table shows the most significant numerical indicators of correlations between the parameters;*
** *a dash means that the value of the correlation between the parameters is less than or equal to ± 0.15; this value is obtained on the basis of correlation analysis of geological and field data and their comparison with the results of geophysical studies of wells*

After that, we will sequentially solve the system of equations (3) in such a way that the sum of the squares of the deviations of the desired values tends to the minimum numerical equivalent:

$$\begin{cases} \sum_{v=1}^{k} n_i \cdot \sigma_i{}^2 = z\left(\overline{x}, \sigma, N\right) \to \min; \\ a_1 = \dfrac{\sum nx \ln n - \sum nx \cdot \sum n \ln n}{\sum nx^2 - \left(\sum nx\right)^2}^{*}; \\ a_2 = \dfrac{\sum nx^2 \ln n - \sum nx^2 \cdot \sum n \ln n}{\sum nx^3 - \sum nx^2 \cdot \sum nx}^{*}; \\ b_1 = \dfrac{\sum nx^4 - (\sum nx^2)^2}{\sum nx^3 - \sum nx^2 \cdot \sum nx}^{*}; \\ b_2 = \dfrac{\sum nx^3 - \sum nx^2 \cdot \sum nx}{\sum nx^2 - \left(\sum nx\right)^2}^{*}; \\ \sigma^2 = \dfrac{b_1 - b_2}{2 \cdot \left(a_1 - a_2\right)}^{*}; \\ \overline{x} = a_1 \cdot \sigma^2 + \dfrac{b^2}{2}^{*} \end{cases} \qquad (3)$$

*Note: for equations marked with *, the subscript is not reflected v*

where a_1, a_1 – auxiliary coefficients; z – a function that combines statistical indicators; k – the number of indicator classes generated based on available data; v – index of parameters Q_o and P.

To determine the degree of mutual influence between producing and injection wells, we propose formula (4) adapted for use in the development of low-yield deposits using special technological modes (KPR) and (or) in unstable operation of deep-pumping equipment:

$$r_\kappa = r_c \left(\frac{\ln \sigma_1 \sqrt{2\pi} + \sum n_1 \, ln \, n_1 + \dfrac{\sum n_1 \overline{x}_1^2 - 2 \cdot \overline{x_1} \cdot \sum n_1 x_1 + \overline{x}_1^2}{2\sigma_1} + C}{\ln \sigma_2 \sqrt{2\pi} + \sum n_2 \, ln \, n_2 + \dfrac{\sum n_2 \overline{x}_2^2 - 2 \cdot \overline{x_2} \cdot \sum n_2 x_2 + \overline{x}_2^2}{2\sigma_2}} \right)^2 \qquad (4)$$

where r_k – the indicator of well interaction; r_c – the well interaction indicator obtained based on the calculation of the Spearman correlation coefficient based on oil production and liquid injection data; a_i – the significance of certain statistical characteristics $(\sigma_i, n_i, \overline{x}_i)$, describing a series of data for producing wells (i=1) and injection pumps (i=2); C – an additional coefficient that takes into account the quantitative value of the correlations between the parameters from table 1 (columns 8, 11) and calculated using formulas (5)-(8) obtained empirically on the basis of these analyte objects:

- when the correlation value r is less than ± 0.15 inclusive:

$$C = 0.9 \cdot \sqrt{r} \qquad (5)$$

- with the value of correlation relationships r from ± 0.151 to ± 0.5 inclusive:

$$C = 0.6 \cdot \sqrt{r} \qquad (6)$$

- with the value of correlation relationships r from ± 0.5 to ± 0.7 inclusive:

$$C = 0.4 \cdot \sqrt{r} \qquad (7)$$

- when the correlation value r is from ± 0.7 to ± 1 inclusive:

$$C = 0.1 \cdot \sqrt{r} \qquad (8)$$

Based on the presented algorithm, the values of the mutual influence indicators between 67 injection wells and more than 100 producing wells were calculated differentially depending on the stratigraphic coincidence. In order to analyze the results obtained and determine their relevance, scattering diagrams in the axes formed by the following statistical characteristics are constructed:

$$\sigma_{1a}^2,\ \sigma_{1b}^2,\ \sigma_{2a}^2,\ \sigma_{2b}^2,\ \overline{x_{1a}},\ \overline{x_{1b}},\ \overline{x_{2a}},\ \overline{x_{2b}}$$

The lower letter indexes a and b denote the values of the characteristics calculated using the formula from the sixth equation of the system (3) and obtained using classical formulas. The lower numeric indexes have the same designation as before (see formula 4). Based on the points formed by the intersection of the values along the abscissa and ordinate axes of the initial sample, generalized regression models (ORMs) were obtained and confidence levels were established (table 2).

Table 2
The results of modeling for three objects of VOS, depending on the stratigraphic confinement

Statistical characteristics along the abscissa and ordinate axes	ORM depending on the stratigraphic location the degree of reliability
σ_{1a}^2 и σ_{2a}^2	Artinsky tier: $\frac{\sigma_{2a}^2 = 0.0876 \cdot \sigma_{1a}^{2\ -1.0765}}{r^2 = 0.784}$ French tier: $\frac{\sigma_{2a}^2 = 0.4525 \cdot e^{-1.561\, \sigma_{1a}^2}}{r^2 = 0.594}$ Eiffel Tier: $\frac{\sigma_{2a}^2 = -0.127 \cdot e^{0.091\, \sigma_{1a}^2}}{r^2 = 0.601}$
σ_{1b}^2 и σ_{2b}^2	Artinsky tier: $\frac{\sigma_{2b}^2 = -0.184 \ln\left(\sigma_{1b}^2\right) + 0.076}{r^2 = 0.405}$ French tier: $\frac{\sigma_{2b}^2 = 2.31 \cdot e^{-0.0561\, \sigma_{1b}^2}}{r^2 = 0.297}$ Eiffel Tier: $\frac{\sigma_{2b}^2 = 1.09 \cdot \sigma_{1b}^{2\ -4.065}}{r^2 = 0.359}$
$\overline{x_{1a}}$ и $\overline{x_{2a}}$	Artinsky tier: $\frac{\overline{x_{2a}} = 0.901 \ln\left(\overline{x_{1a}}\right) + 1.8}{r^2 = 0.543}$ French tier: $\frac{\overline{x_{2a}} = 8.039 \cdot e^{-2.0561\, \overline{x_{1a}}}}{r^2 = 0.901}$ Eiffel Tier: $\frac{\overline{x_{2a}} = 0.901 \ln\left(\overline{x_{1a}}\right) + 1.8}{r^2 = 0.459}$
$\overline{x_{1b}}$ и $\overline{x_{2b}}$	Artinsky tier: $\frac{\overline{x_{2b}} = 0.049 \cdot e^{-1.0361\, \overline{x_{1b}}}}{r^2 = 0.304}$ French tier: $\frac{\overline{x_{2b}} = -2.6 \cdot e^{1.1\, \overline{x_{1a}}}}{r^2 = 0.654}$ Eiffel Tier: $\frac{\overline{x_{2a}} = 0.012 \ln\left(\overline{x_{1a}}\right) + 12.4}{r^2 = 0.221}$

** The table shows the regressions with the highest accuracy of the approximation*

Conclusion

Interpreting the above results, we note that for deposits associated with the Artinsky, Fransky and Eiffel tiers, the degree of reliability of the models increased on average from 1.12 to 1.23 times, and in most cases the canonical form of the regression model has changed. When comparing the calculated values of the mutual influence of wells g_k with real field data, the following was established:

- for the deposits of the Artinsky and Eiffel tiers, a certain pattern can be traced, which consists in the fact that wells operated in the KPR mode for less than 3 months with a starting flow rate of up to 6 tons/day inclusive, there is a discrepancy in the quantitative and qualitative assessment of mutual influence (denoted as t). This is due to the peculiarities of the geological structure of the objects, in particular, the significant variability of the parameters within the territory of the deposit;
- for deposits of the Fran tier, the discrepancy in the complex indicator *t* is present in those wells where hydraulic fracturing operations were carried out or the process of secondary opening of productive formations was carried out using hydroblasting perforation; this suggests that when exposed to carbonate reservoirs, the disturbance propagation zone is not limited by the radius of well drainage and as the deposit is exploited, it can It can be enlarged both vertically and laterally.

In general, for low-yielding deposits of VOC, we can note a general tendency for the results obtained empirically to coincide with the conclusions established during tracer studies using injection of a labeled substance, which tells us about the relevance and relevance of using the presented hybrid algorithm.

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